# Constellation-X and Supernova Remnants

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# Con-X Science Objectives

- Map abundances and velocity distributions
  - – Extended SNRs
  - – Species: Carbon to Zinc
    - Trace elements: P, Cl, K, Ti, Cr, Mn, Ni
- Identify and study sites of cosmic ray acceleration in young SNRs
- Type SNRs in external galaxies (at the distance of Virgo ... according to web site)
  - – M31/M33 possible, but not much further

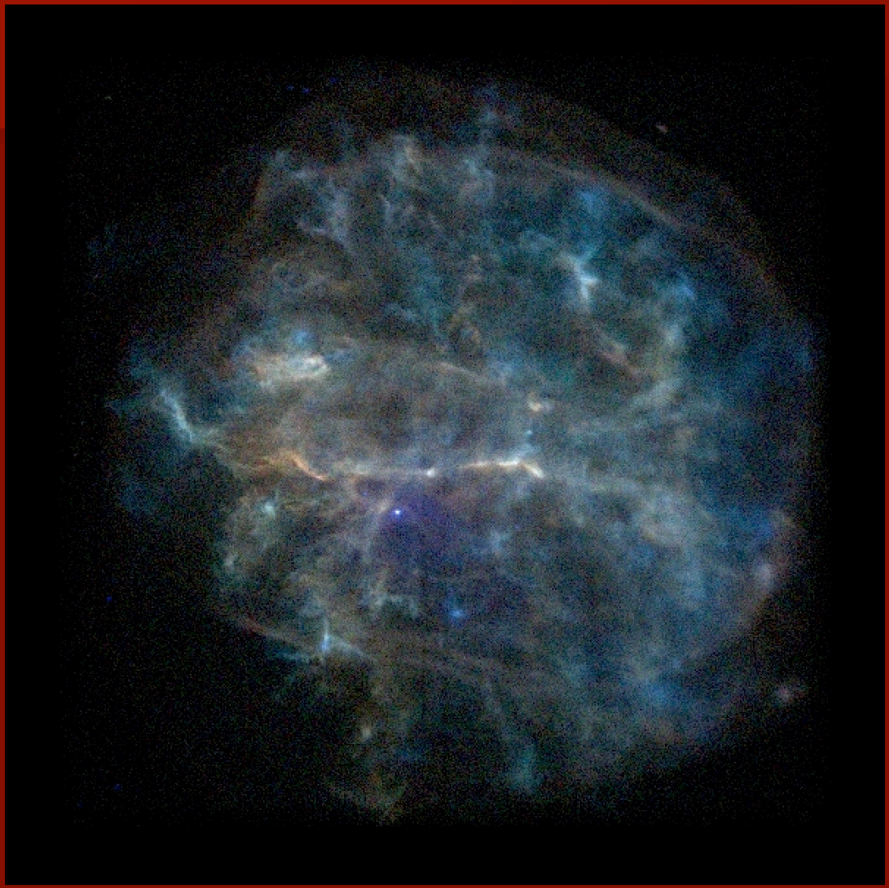
# Additional Topics

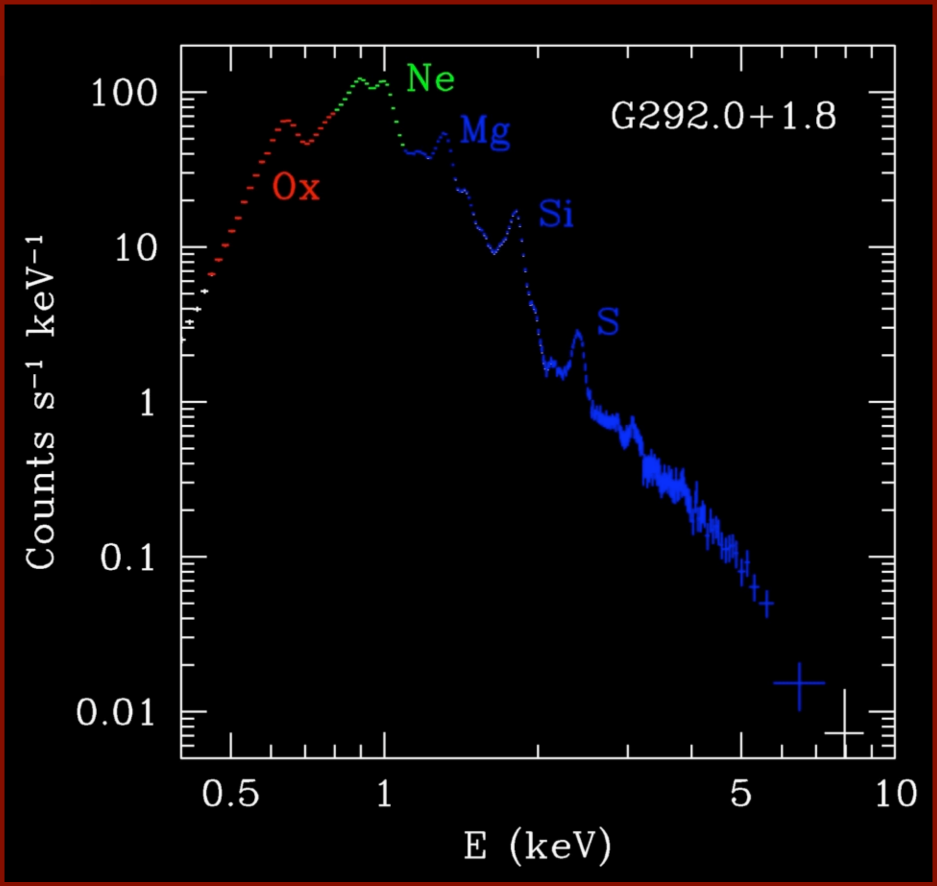
- Shock Physics
  - Initial electron/proton/ion temperature equilibration
  - Timescale for subsequent temperature equilibration post-shock
  - Evolution of gas phase elemental abundances
- Pulsar wind nebula (PWN) and SNR interactions and evolution
- Galactic Center and Galactic Ridge

# Example Con-X Science Cases

- Core collapse SNR: G292.0+1.8
  - O-rich in optical; O-, Ne-, & Mg-rich in X-rays
  - High velocity ejecta: v~1000 km/s
  - 135-ms pulsar and PWN
- Type Ia SN Remnant: DEM L71
  - Fe-rich ejecta in center surrounded by shocked ISM – measure Fe expansion velocity
  - Te/Tp temp. equilibration at ISM shock
- Clumping in Remnants of SN Ia

# Oxygen-Rich SNR G292.0+1.8






Age~3000 yrs, 137 ms pulsar

Hughes et al. 2001, Park et al 2001, Gonzalez & Safi-Harb 2003, Park et al. 2003

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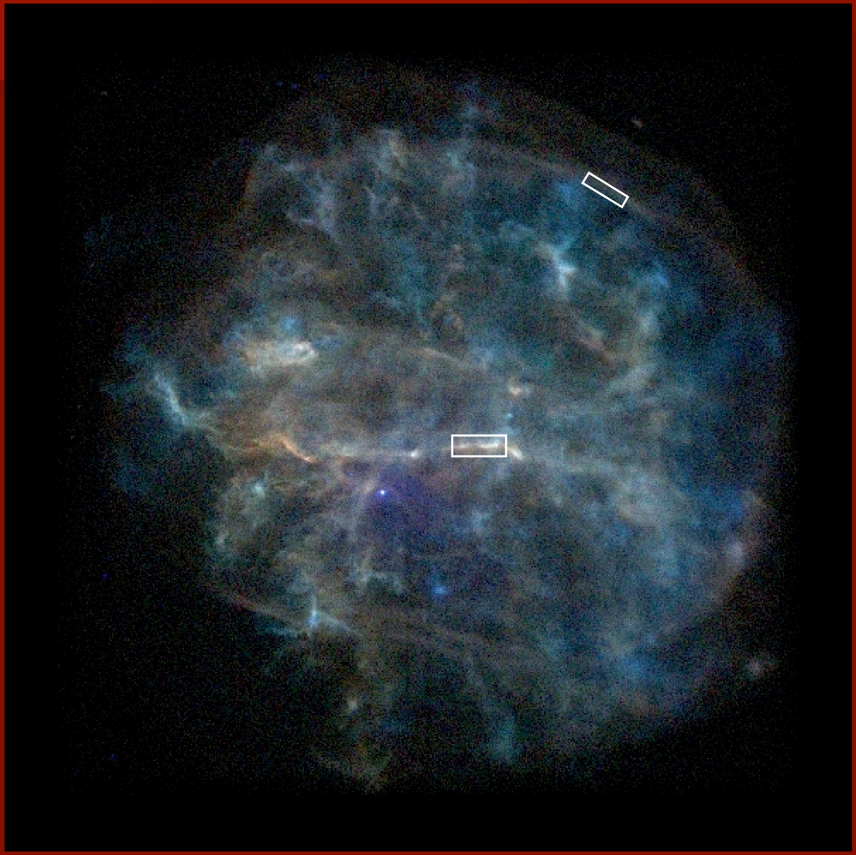
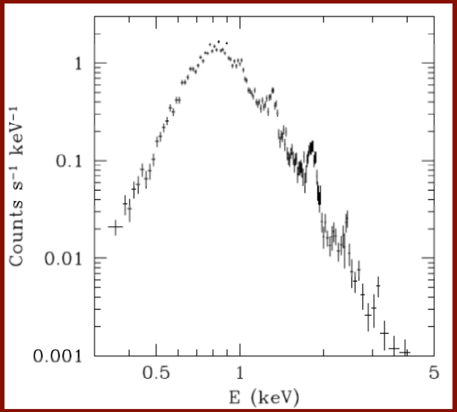


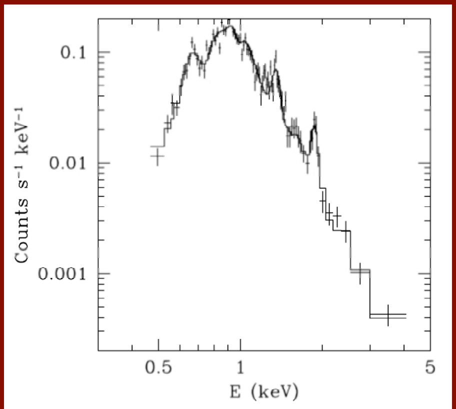
## Normal Composition, CSM

Central bright bar, $n_e$~40 cm$^{-3}$ (an axisymmetric stellar wind?)

Thin, circumferential filaments enclose ejecta-dominated material (red/blue supergiant wind boundary?)

Blast wave $n_e$~0.2-0.5 cm$^{-3}$



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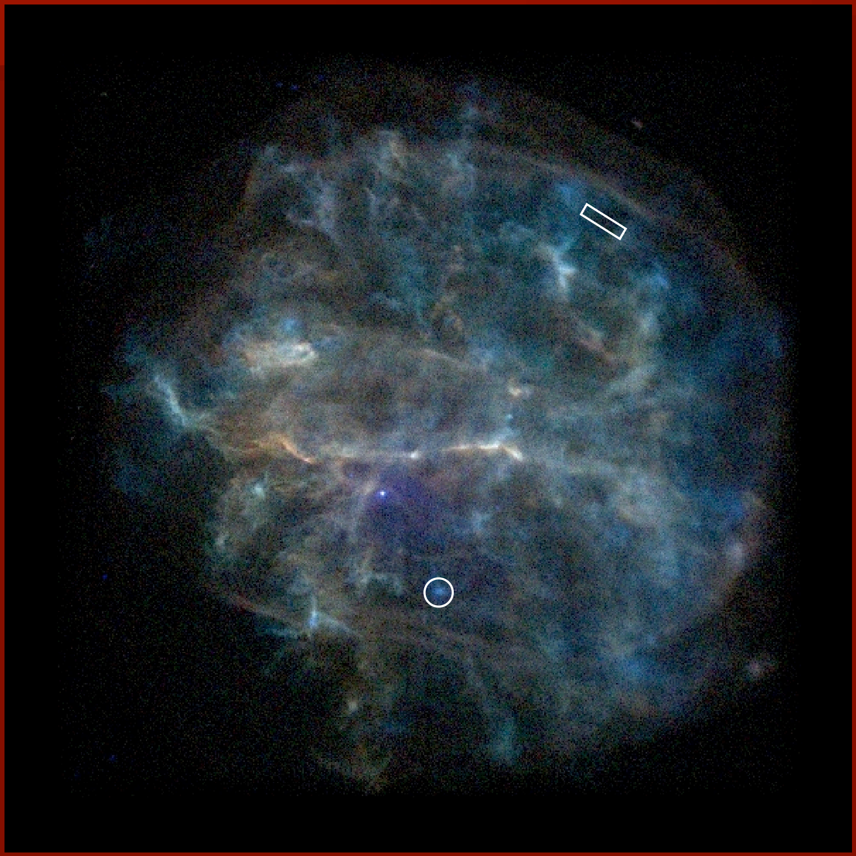


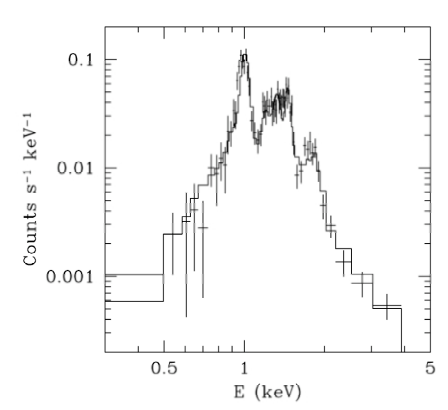
## Ejecta

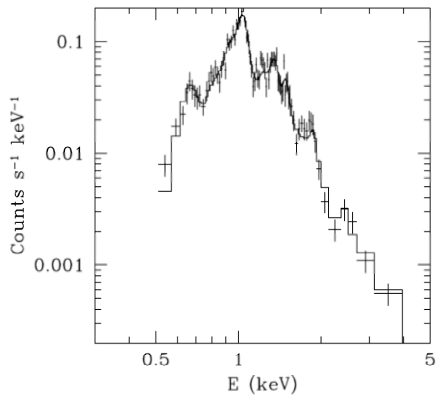
Rich in O, Ne, and Mg, some Si

[O]/[Ne] < 1

No Si-rich or Fe-rich ejecta, like in Cas A

Nucleosynthesis during hydrostatic evol. of 20-25 solar mass progenitor



# Core Collapse SN Science

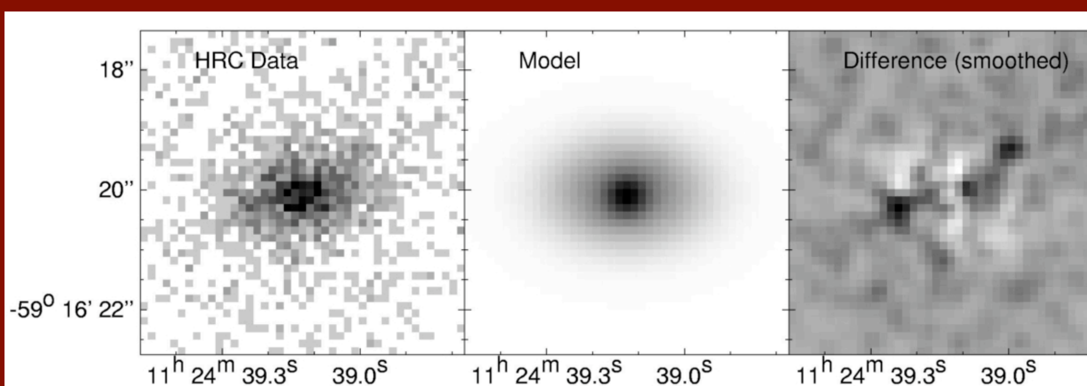
What is the interaction between the PWN and the SNR in G292.0+1.8?

Pressure in PWN < $10^{-9}$ dyne/cm$^2$

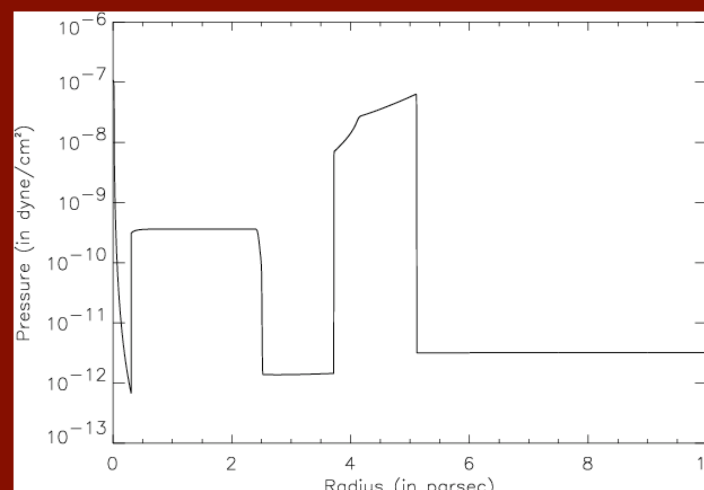
Pressure in ejecta/shocked CSM: $6\times10^{-9}$ to $9\times10^{-8}$ dyne/cm$^2$

Conclusion: PWN is sweeping up unshocked cold ejecta.

We see no optical- or X-ray-emitting Fe-rich ejecta in this remnant (unlike Cas A). Is it because the Fe lies in this region of cold ejecta between the PWN and the reverse shock? Use Con-X's high sensitivity to detect this cold material in absorption against the background synchrotron nebula. This would be a useful probe of this material and would confirm the evolutionary state of the PWN/SNR.

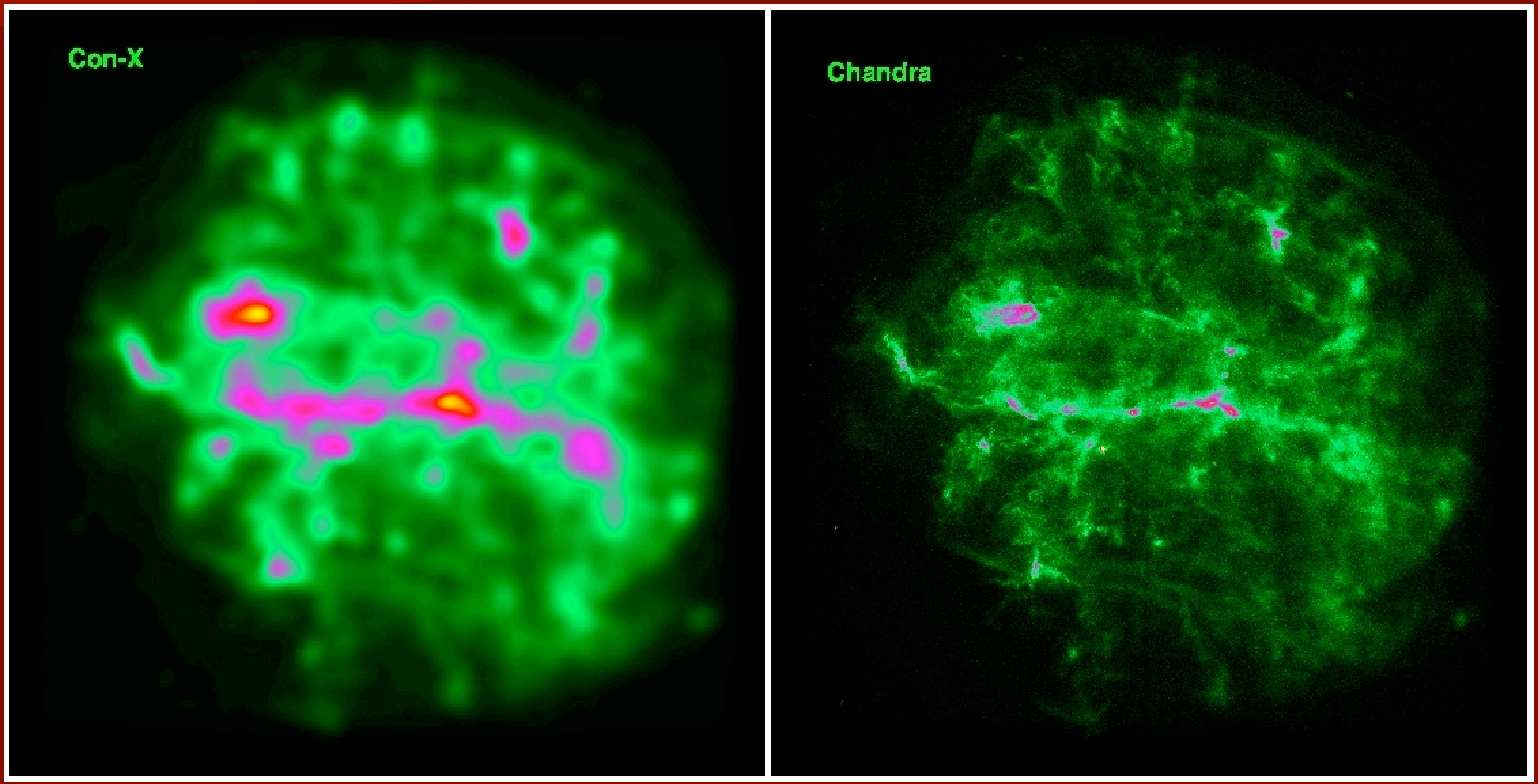



Hughes et al. 2003, ApJL, 591, L139



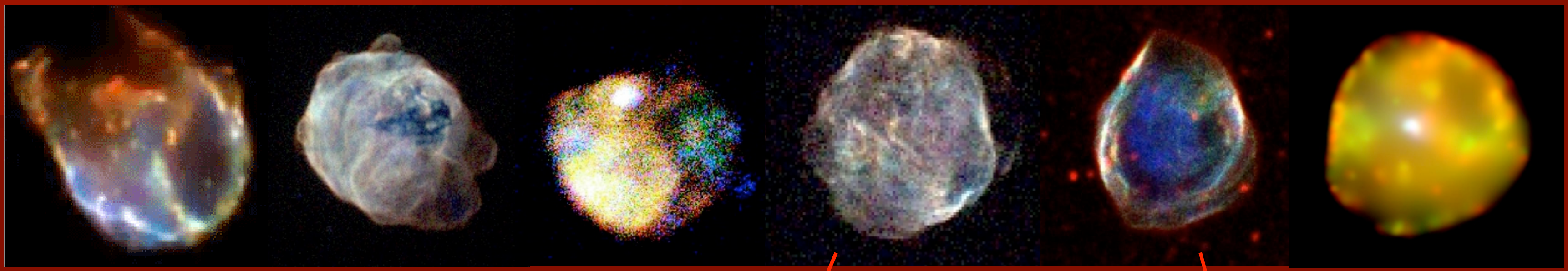

Van der Swaluw et al. 2001, A&A, 380, 309

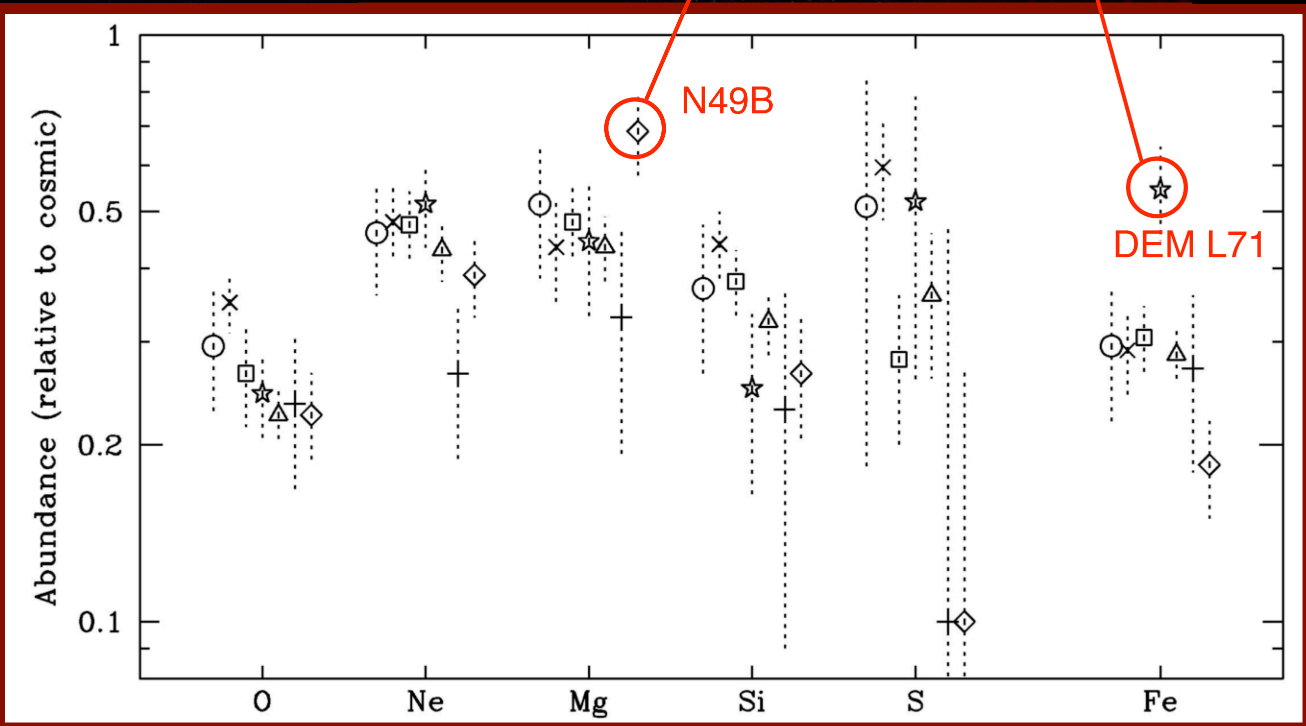
# Contrasting Views of G292.0+1.8



# LMC SNRs: Integrated Abundances

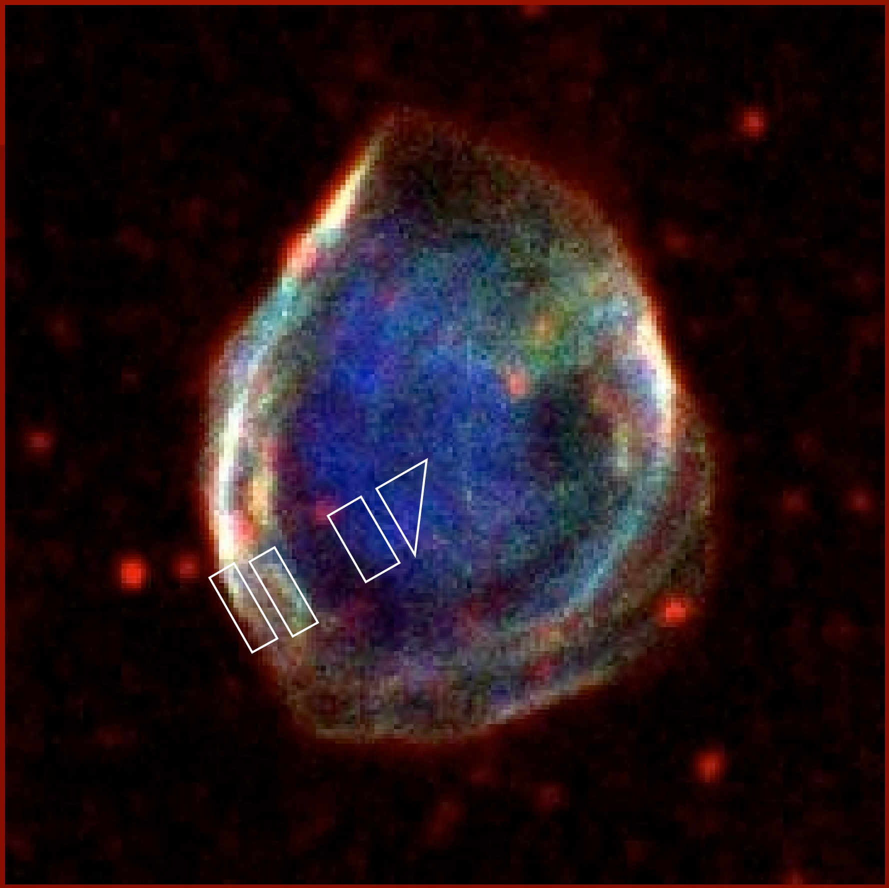
From fits to ASCA global X-ray spectra of evolved LMC remnants





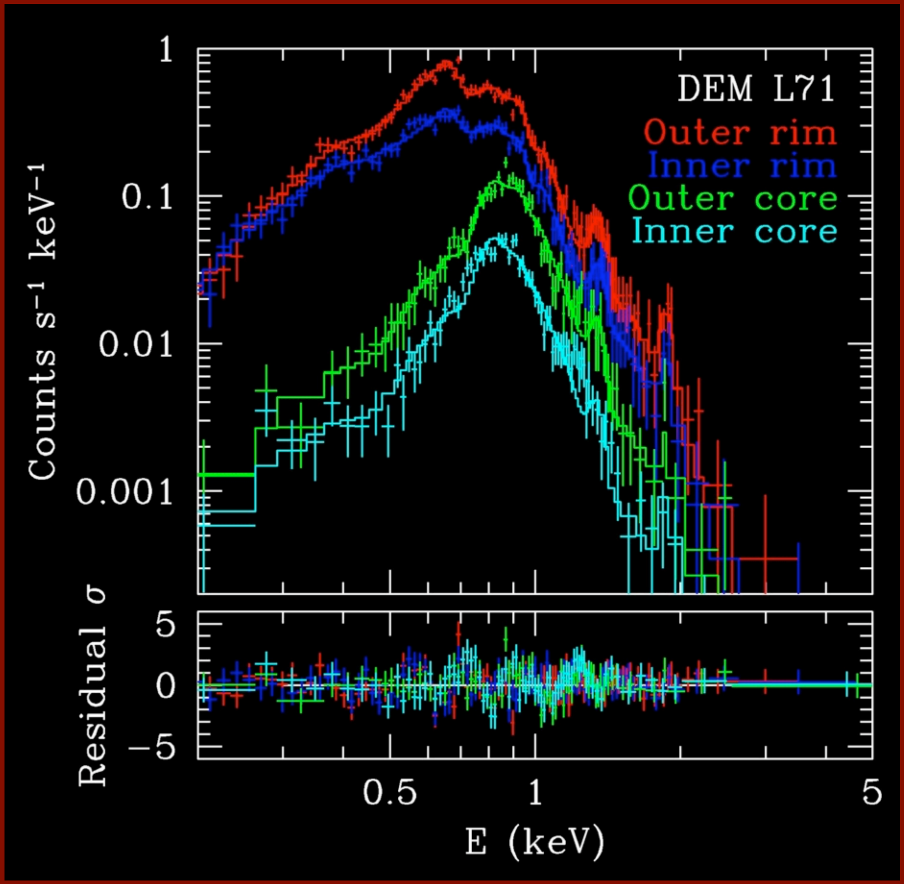

Hughes, Hayashi, & Koyama 1998, ApJ, 505, 732

# DEM L71: Fe-Rich Ejecta



Hughes, Ghavamian, Rakowski, & Slane 2003, ApJ, 582, L95

Middle-aged LMC SNR
- 36" (8.7 pc) in radius
- 4,000 yrs old

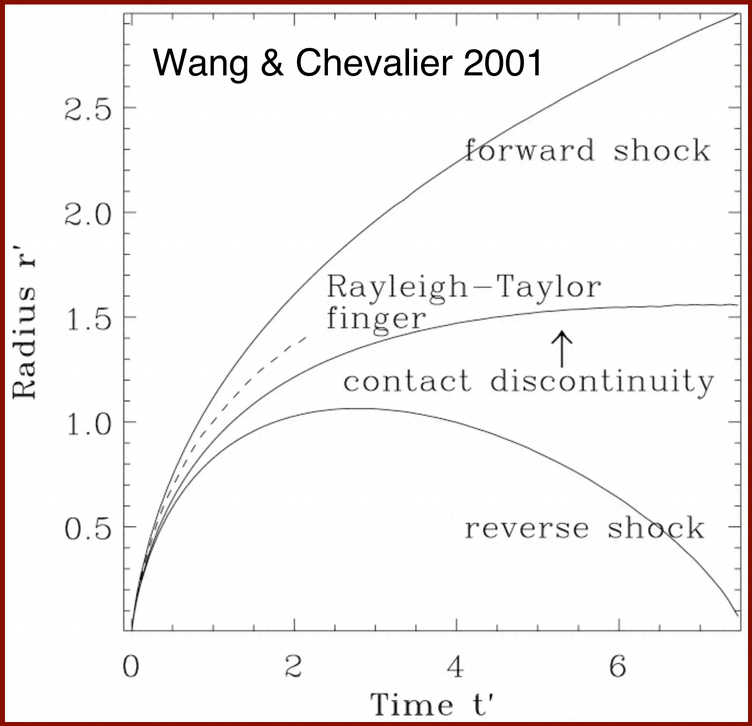


# Properties of DEM L71 Ejecta

- Outer rims: lowered abundances, ~0.2 solar (LMC ISM)
- Core: enhanced Fe abundance, [Fe]/[O] > 5 times solar (ejecta)
- Thick elliptical shell, 32” by 40” across (3.9 pc by 4.8 pc)
- Dynamical mass estimate

r’ ~ 3.0

$M_{ej} = 1.1\ M_{ch}\ (n/0.5\ cm^{-3})$




- EM mass estimate

$EM \sim n_e\ n_{Fe}\ V$

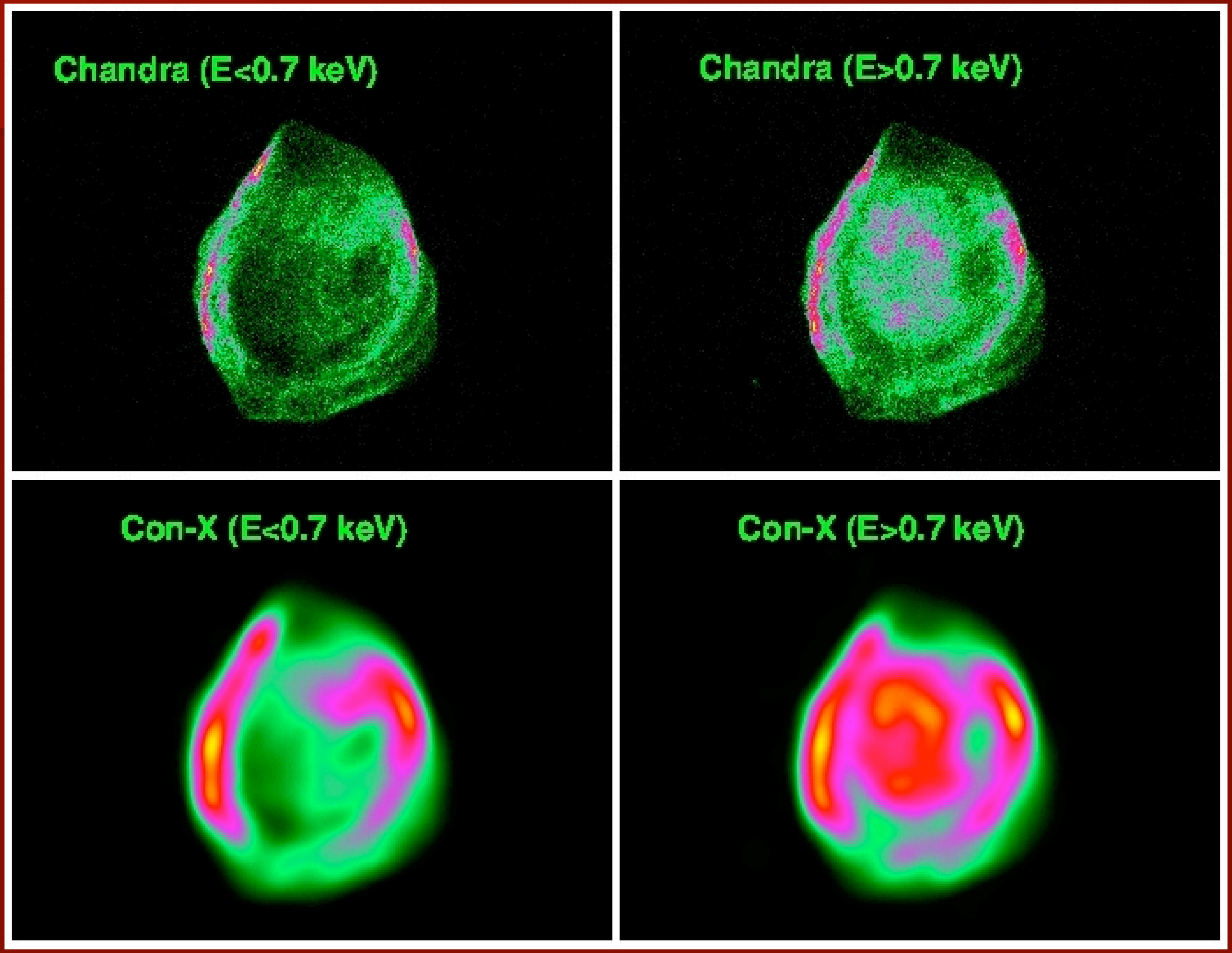
$M_{Fe} < 2\ M_{sun}$

- Main error: source of electrons

Fe-rich, low mass → SN Ia

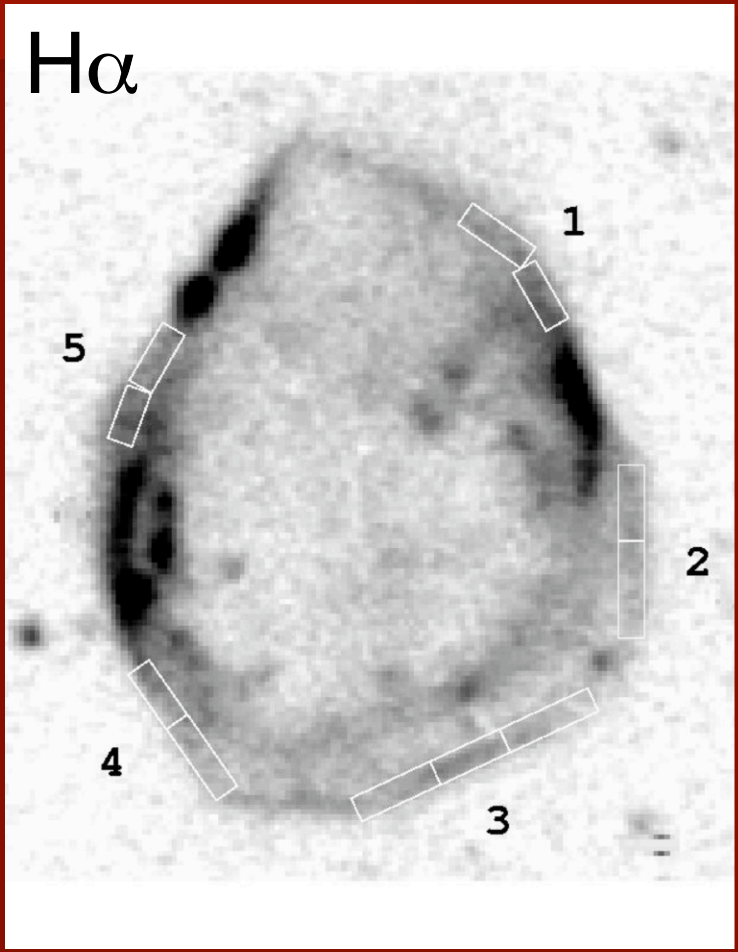
Velocity low ~ 100 km/s

# Contrasting Views of DEM L71

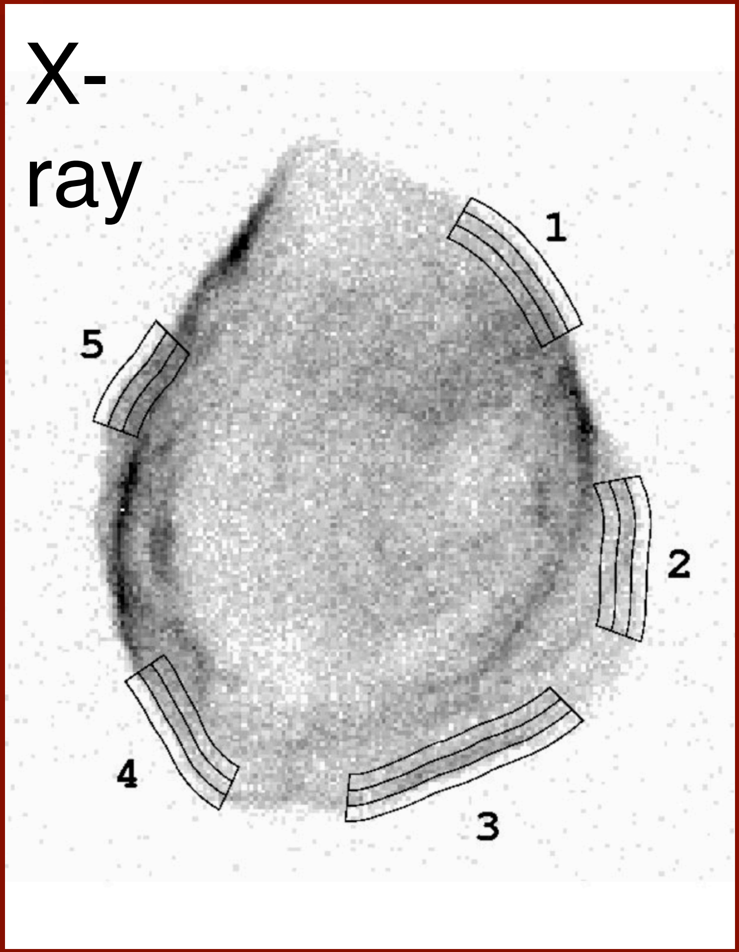


# DEM L71: Shock Physics

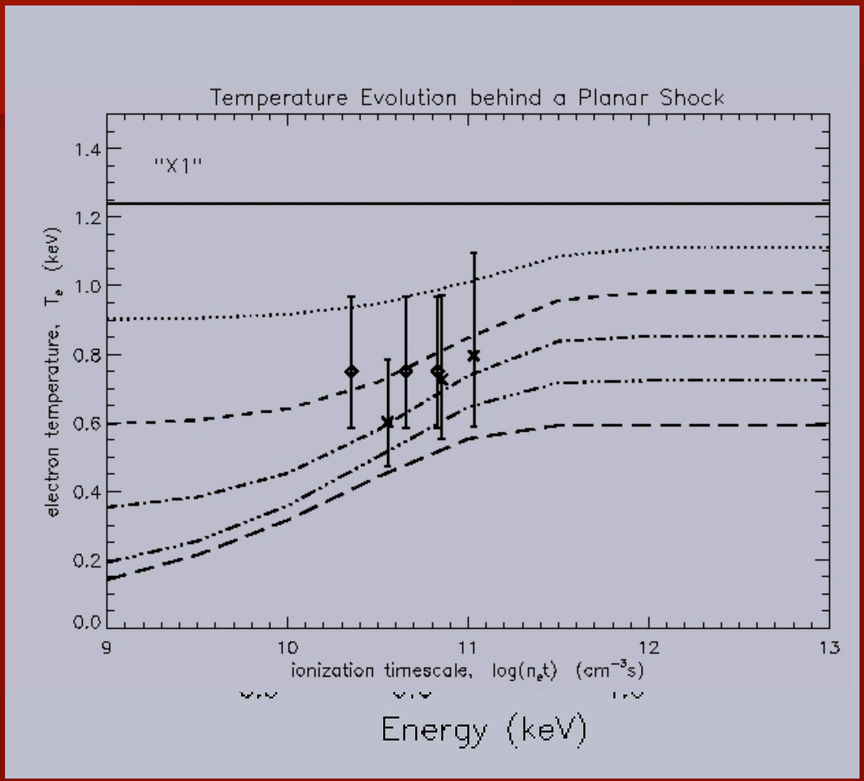
Nonradiative Balmer-dominated shock
Measure post-shock proton temperature




X-ray emission from thermal bremsstralung
Measure post-shock electron temperature



# Constraining the Electron Temperature

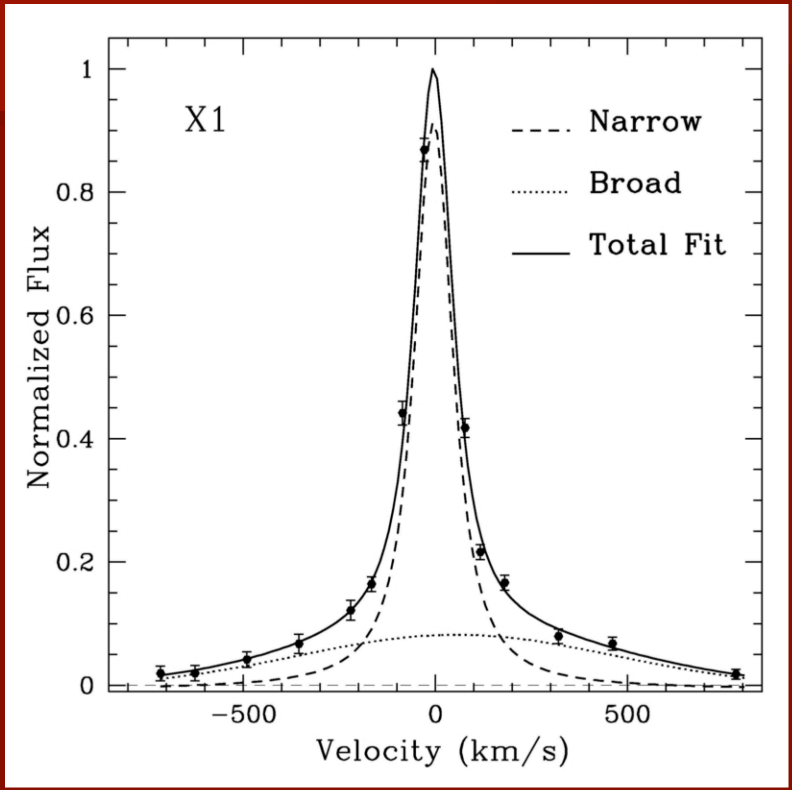



Rakowski, Ghavamian, & Hughes 2003.

- Fit plasma shock models to 3 spatial zones to follow evolution of $T_e$
- Study 5 azimuthal regions with sufficient Chandra statistics and broad H$\alpha$ component
- Available data cannot constrain $T_e$ gradients

- Data do determine mean $T_e$
- Suggest partial to complete temperature equilibration

# Nonradiative Balmer Shocks




Ghavamian, Rakowski, Hughes, and Williams 2003.

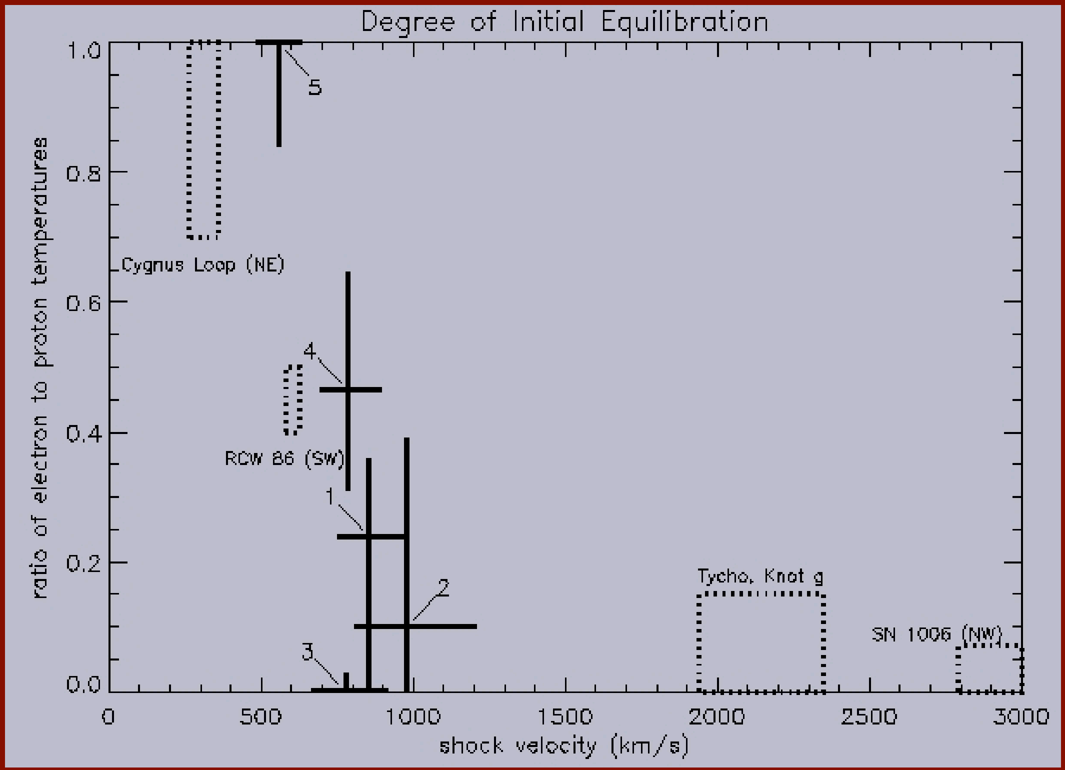
- Nonradiative means that a radiative (cooling) zone does not form
- Low density (partially neutral) gas
- High velocity shocks
- Narrow component: cold H I overrun by shock, collisionally excited
- Broad component: hot postshock protons that charge exchange with cold H I

(Chevalier & Raymond 1978; Chevalier, Kirshner, & Raymond 1980)

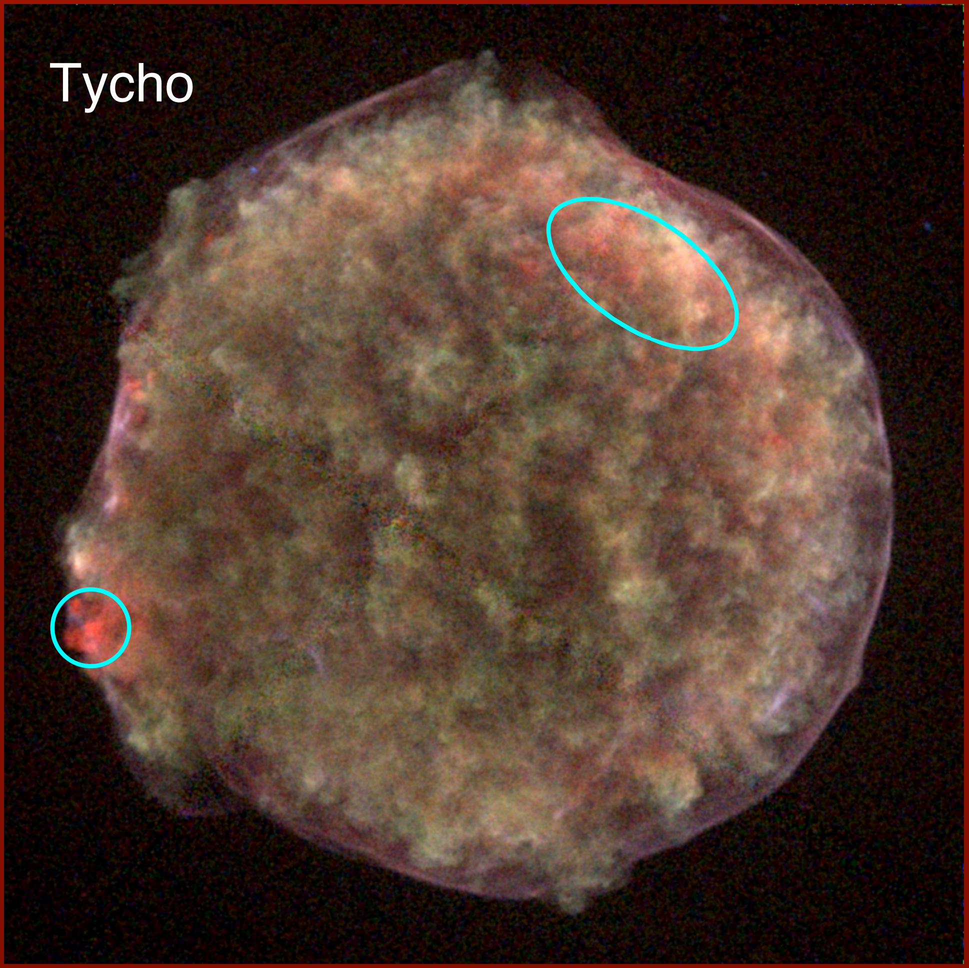
Width of broad component yields post shock proton temperature

# Results on $T_e/T_p$ from DEM L71

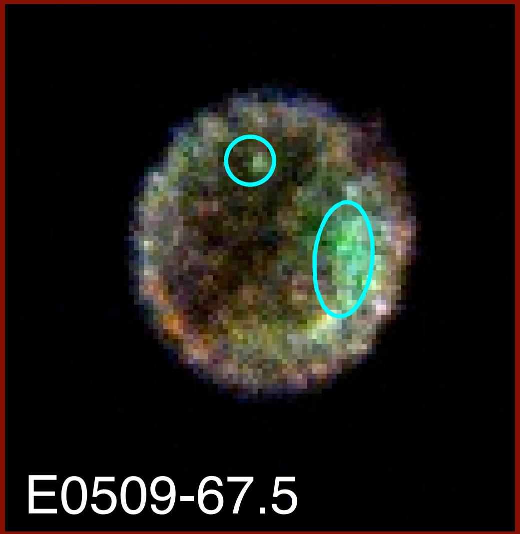
- Shows trend: higher equilibration for slower shocks
- X-ray/Hα results consistent with other purely Hα ones



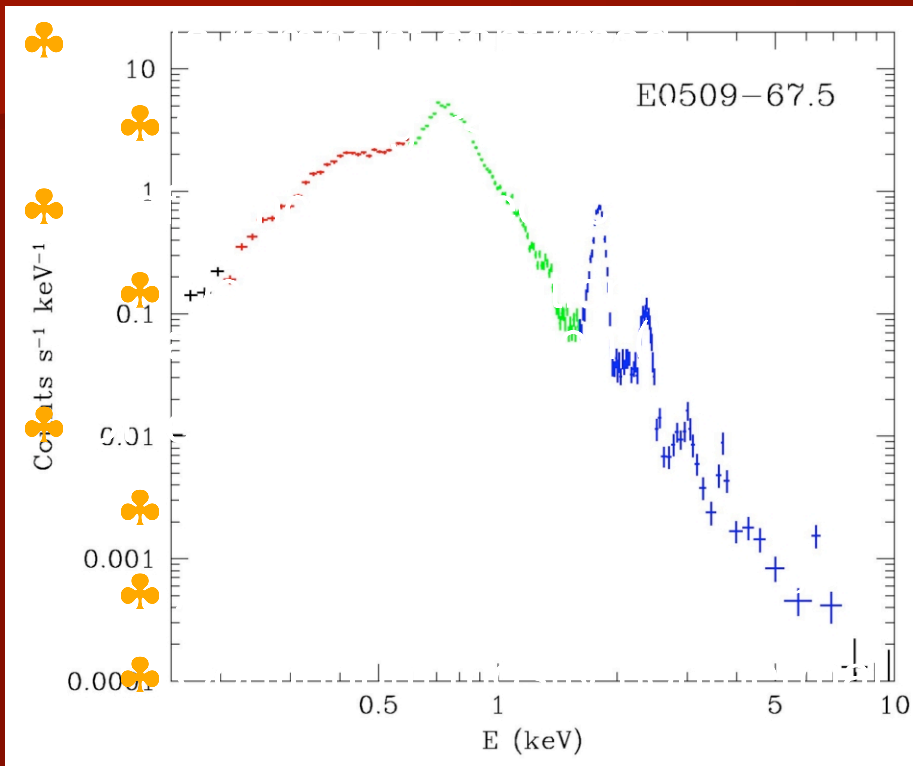
# Identifying Remnants of SN Ia

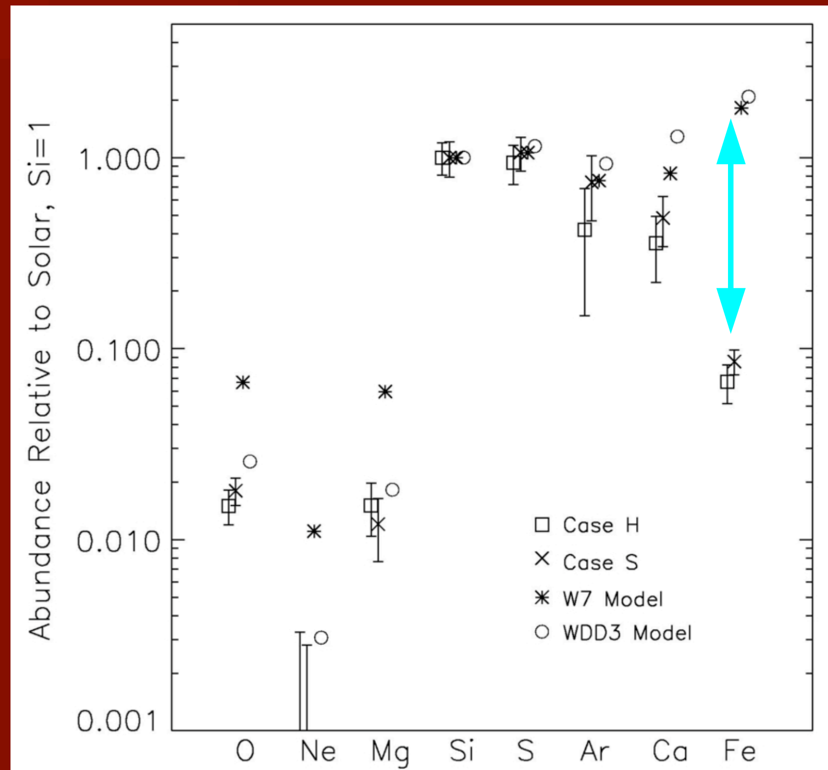



- Balmer-dominated SNRs (partially neutral ISM)
- Ejecta abundances (Si and Fe rich, poor in O and Ne)
- Remnant structure (uniform ISM, “smoother” ejecta, modest spectral variation)



# SN Ia Spectra and Abundances



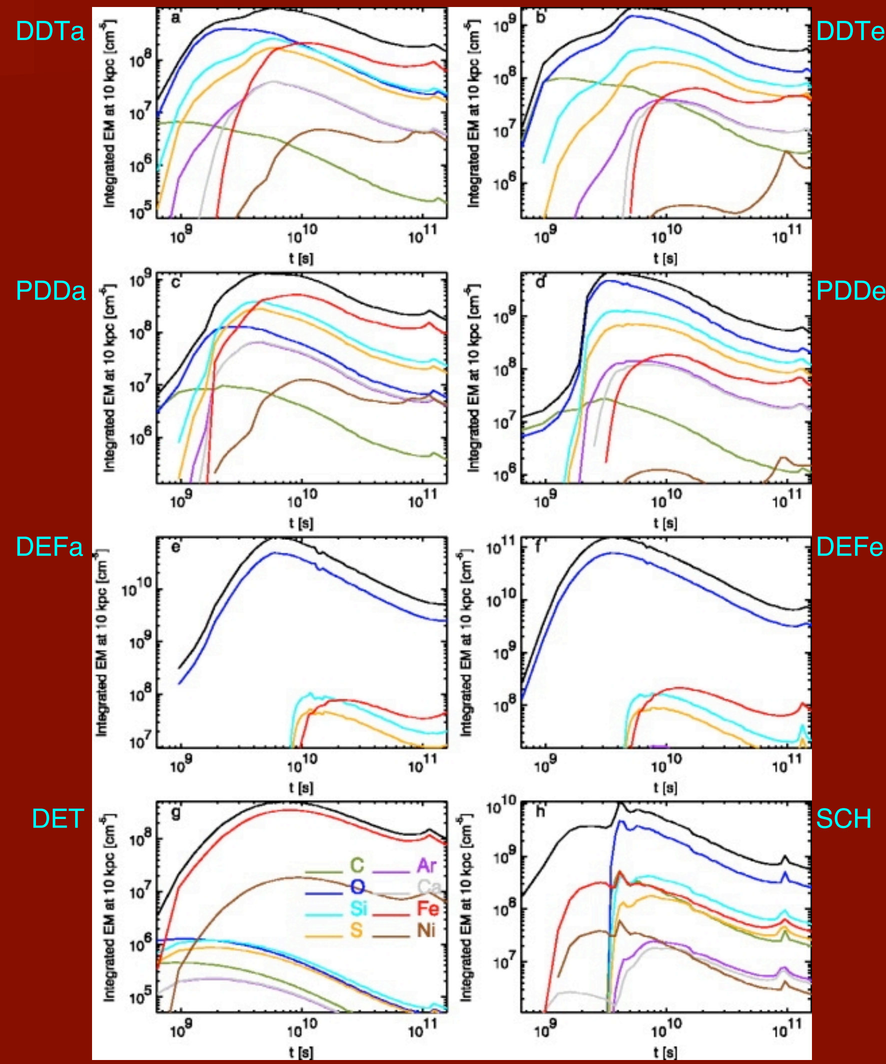

W7: Nomoto et al 1984, Thielemann et al 1993

WDD3: Iwamoto et al 1999

Case H & S (Spectral fit): Warren & Hughes 2003

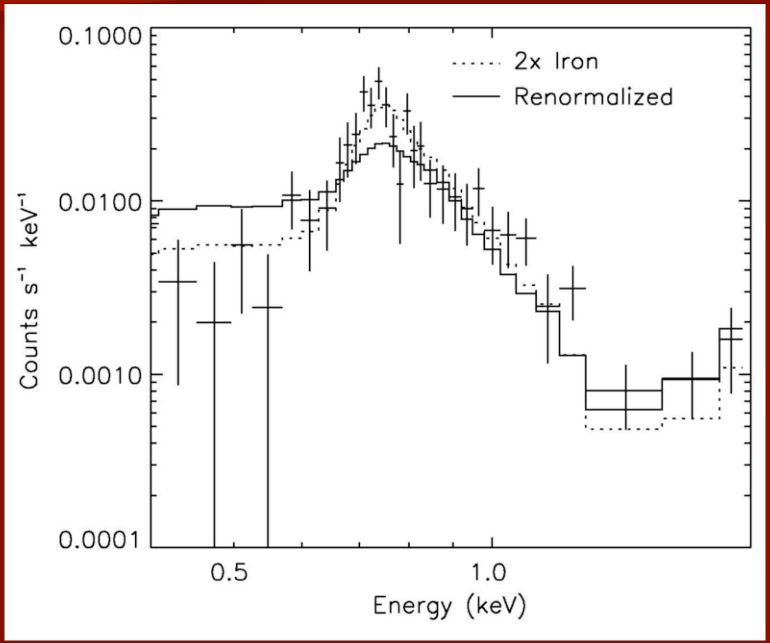
# Getting to the Physics of SNe Ia

- Some variation in SN Ia explosion mechanism needed to explain light curves (e.g., density when flame speed transitions from deflagration to detonation)
- Strong compositional differences for different explosion types
- Manifested at different times during evolution of SNR (Badenes et al. 2003)
- Tycho, E0509-67.5, and DEM L71 X-ray spectra favor delayed detonation models



# Origin of SN Ia Ejecta Clumps

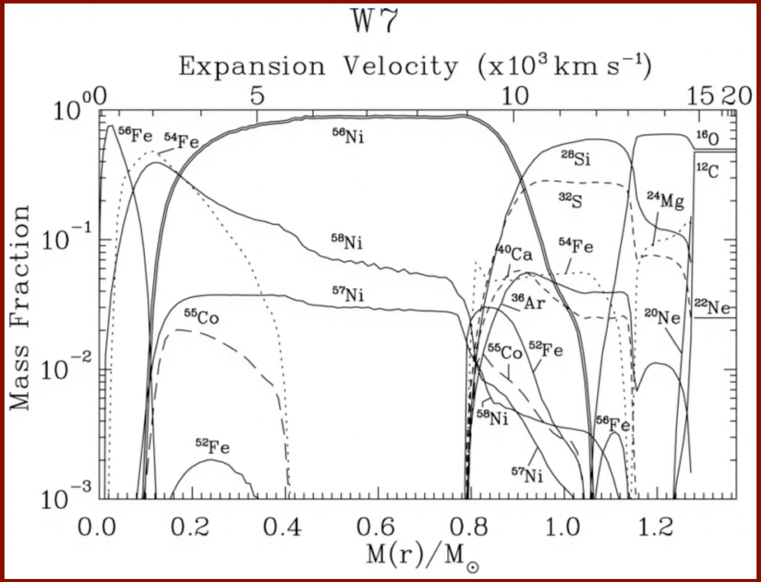
*Chandra* spectrum of brightest isolated clump in E0509-67.5




Warren & Hughes 2003, ApJ, submitted

Clumps originate in region between Si+S and Fe rich zones where nickel bubble pushes

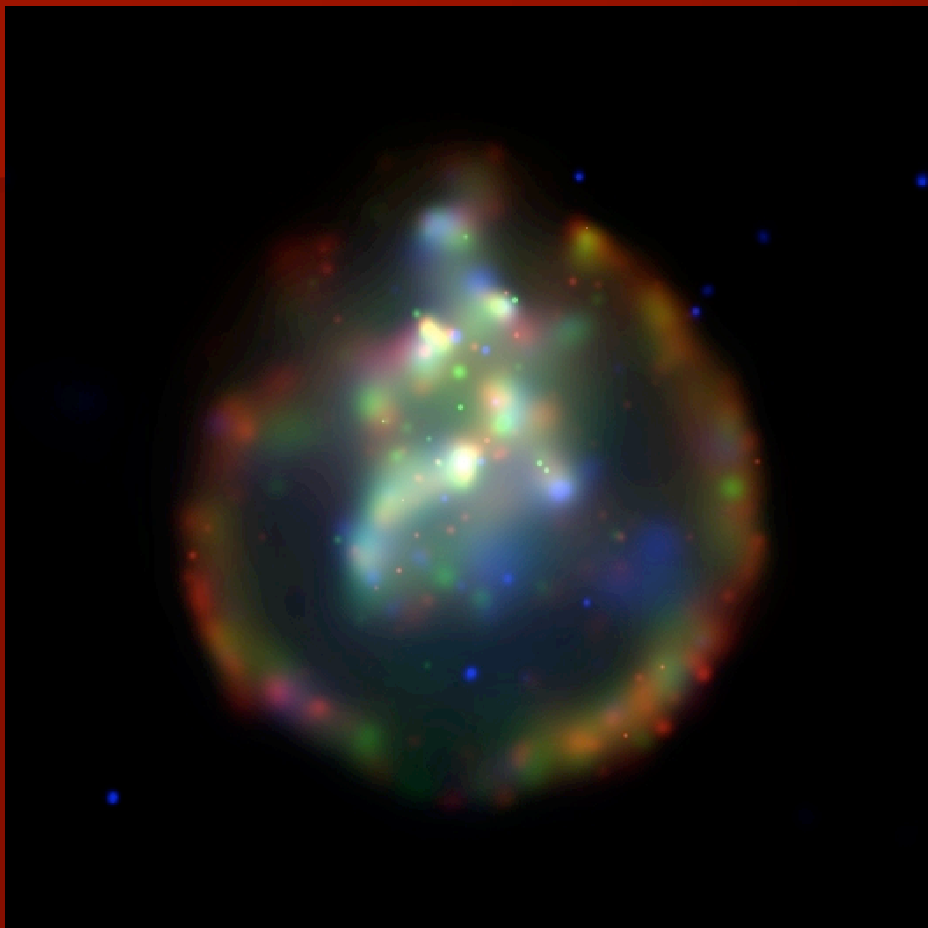
- Bright clump in E0509-67.5 shows Fe enhanced by only factor of ~2
- Clumps along eastern edge of Tycho show varying ratios of Si+S/Fe abundances (Decourchelle et al. 2001)
- No evidence for pure Si or Fe clumps



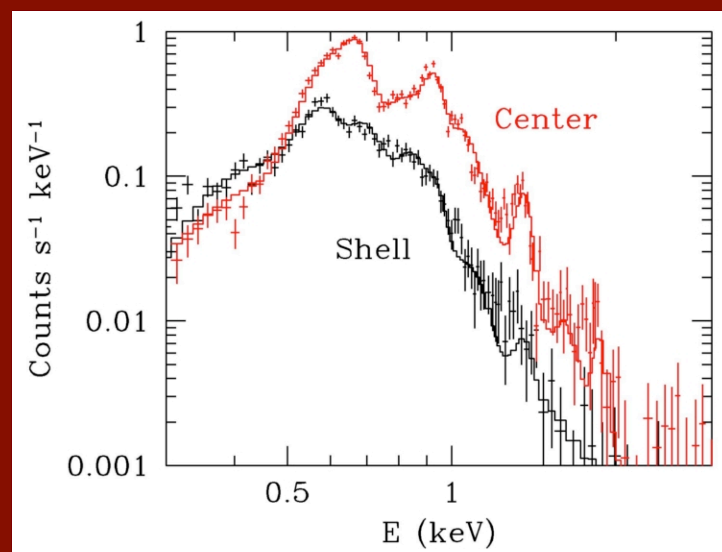
# Constellation-X Capabilities: Requirements for SNR studies

- Spatial resolution
  - <5” (minimum for LMC SNRs)
- Field of view
  - 15’ or more for Galactic SNRs
- High count rate tolerance
  - Weak lines in bright sources
- Spectral resolution
  - Velocity resolution ~100 km/s (from DEM L71 Fe ejecta)
- Significant low energy (< 1keV) response
  - Many SNRs have kT<1 keV

# SNR 0103-72.6



- Middle-aged SNR
  - 87” (25 pc) in radius
  - >10,000 yrs old (?)
- Circular rim
  - SMC composition
- Central bright region
  - O, Ne, Mg, Si-rich ejecta
  - No Fe enhancement




Park, et al 2003, ApJ, in prep.